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Failure Analysis of Leaking Stainless Steel Pump Casing

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MSE 489 Senior Design Class Project 2

Final Project Report Failure Analysis of Leaking Stainless Steel Pump Casing

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Abstract

The purpose of this project is to determine the cause of failure for a leaking CN7M stainless steel pump housing. A chemical analysis was done to confirm the composition of the alloy, the pump housing was broken to see the fracture surface of internal cracks, and metallography was done to determine if a solution treatment had been performed. It was found that the chemical composition was very similar to that of the standard and that the pump failed with intergranular fracture. The metallography showed carbides in and around grains making the material susceptible to intergranular attack. Intergranular corrosion led to cracking which caused the pump to leak.

Introduction

Project Background

The stainless steel pump casing being analyzed in this project was taken from a centrifugal pump used at Sea World to circulate artificial sea water in Baby Shamu's tank. This pump began leaking after about one year of service, but other similar pumps worked well for several years. The failed pump was cast using CN7M which is a special austenitic casting alloy designed for use in corrosive environments especially sulfuric acid and other reducing chemicals [2]. The leaking was caused by cracks in the pump casing shown in Figure 1.

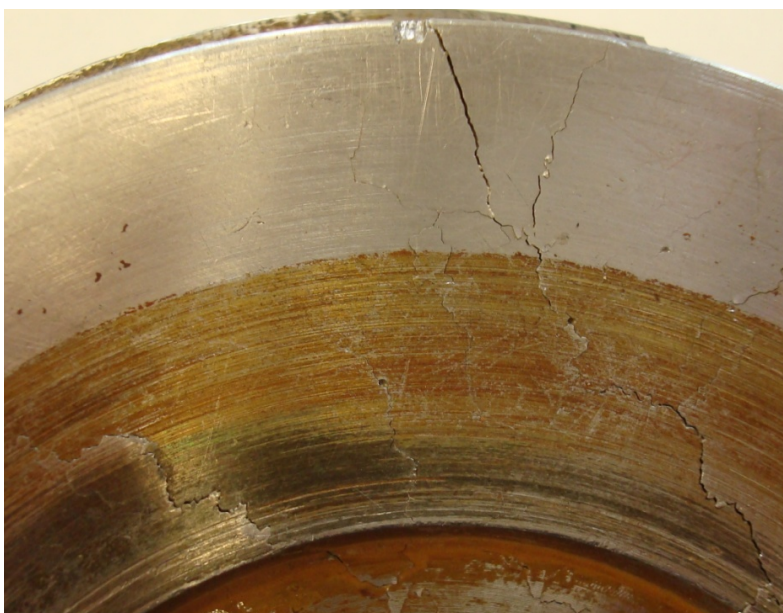


Figure 1: Cracks in the casing of a centrifugal pump.

Centrifugal Pump

A centrifugal pump works by increasing the pressure of a fluid with a rotating impeller inside the housing. This causes the fluid to flow through the pump and out to the desired location. In this case, the pump was simply circulating artificial sea water in a large tank. An example of an assembled centrifugal pump is shown in Figure 2. The flow of fluid in a centrifugal pump is in a circular motion leading to the name “centrifugal.”

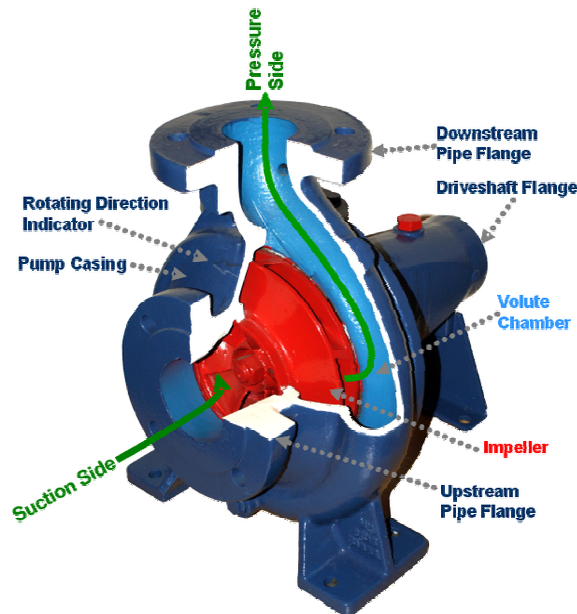


Figure 2: This picture shows the essential parts of a centrifugal pump.

Possible Causes for Cracking

In a case study on premature failure in castings (1980) summarized in ASTM Handbook 11, intergranular corrosion caused about 50 % of the failures in corrosion resistant cast parts. Between 30% and 40% of failure was caused by solidification-type discontinuities such as hot tears, cracks, porosity, and shrinkage. Some failures were attributed to repair welds, but the cast pump in this study did not contain any welds. Failure was rarely associated with crevice corrosion and stress corrosion cracking in this study. (pp 147-148)

CN7M Stainless Steel

The stainless steel used to make the pump housing is CN7M which is a corrosion resistant austenitic casting alloy. The composition of this alloy is given in ASTM A743/A743M – 06 and is presented in Table 1. The notes in the third column were taken from ASM Handbook 13 [] page 700 and *Atlas of Cast Corrosion-Resistant Alloy Microstructures* reference 3 page 50, 87[].

Table 1: Composition of CN7M as Reported by ASTM A743M-06		
Element	Amount (%)	Notes
Carbon	≤ 0.070	Low carbon for reduced Sensitization
Chromium	19.0 – 22.0	Corrosion resistance
Copper	3.0 – 4.0	Corrosion resistance in sulfuric or organic acids
Iron	37.3 – 48.5	As a remainder
Manganese	≤ 1.50	Promotes austenite stability
Molybdenum	2.0 – 3.0	Pitting Resistance and corrosion resistance in sulfuric or organic acids.
Nickel	27.5 – 30.5	Corrosion resistance
Phosphorous	≤ 0.040	Keep to a minimum
Silicon	≤ 1.50	Fluidity during pouring and resistance to hot cracking during cooling
Sulfur	≤ 0.040	Keep to a minimum

The alloying elements listed above are used to increase strength and corrosion resistance, as well as to extend the austenite phase field to room temperature [2]. Since this alloy is austenitic, it should not be magnetic and initial observations confirmed this. According to ASTM A743M-06, the heat treatment procedure is as follows: “Heat to 2050°F (1120°C) minimum, hold for sufficient time to heat casting to temperature, quench in water or rapid cool by other means.” This is also called a solution treatment because it ensures the solution of carbides that precipitate at lower temperatures. According to the *Atlas of Cast Corrosion-Resistant Alloy Microstructures*, for CN7M to have the maximum corrosion resistance and to protect against intergranular attack, carbides should be well dissolved [2].

Objectives

The purpose of this project is to determine the cause of failure of the leaking CN7M pump housing by determining the chemical composition, creating and analyzing a fracture surface, looking for carbides in the microstructure.

Methods

The as-received condition of the pump housing is shown in Figure 3. Two sections were cut from the pump housing for analyzation. The first was a large cross-section showing internal grains and cracks. This sample was electrolytically etched with Oxalic acid at 6 volts and 6 amps for about 5-10 seconds. The second was a smaller section used for an approximate chemical analysis by using energy dispersive spectroscopy (EDS).

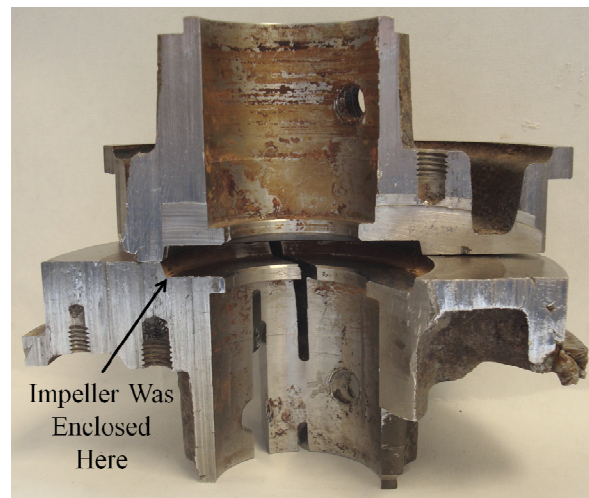


Figure 3: As received pump housing. Impeller location is indicated on figure.

After these pieces has been cut, a fracture surface was obtained by cooling a part of the pump housing in liquid nitrogen and hitting it with a mallet until it fractured (Figure 4). Several small pieces (circled in Figure 4) were recovered and analyzed using a scanning electron microscope (SEM).



Figure 4: Broken pieces after fracture. The circles pieces were used for SEM work.

Results and Discussion

Electron Dispersive Spectroscopy

The EDS results are shown in Table 2 and Figure 5. The results are very close to the standard, but the chromium and copper are low and the nickel is high. Since EDS is only an approximate measure of composition and the differences are not large, these inconsistencies are not critical.

Table 2: Measured Composition			
	Standard	Measured	
Carbon	≤ 0.070	0	Good
Chromium	19.0 – 22.0	17.42	Low
Copper	3.0 – 4.0	2.4	Low
Iron	37.3 – 48.5	41.46	Good
Manganese	≤ 1.50	0.37	Good
Molybdenum	2.0 – 3.0	2.03	Good
Nickel	27.5 – 30.5	34.99	High
Phosphorous	≤ 0.040	0	Good
Silicon	≤ 1.50	1.31	Good
Sulfur	≤ 0.040	0	Good

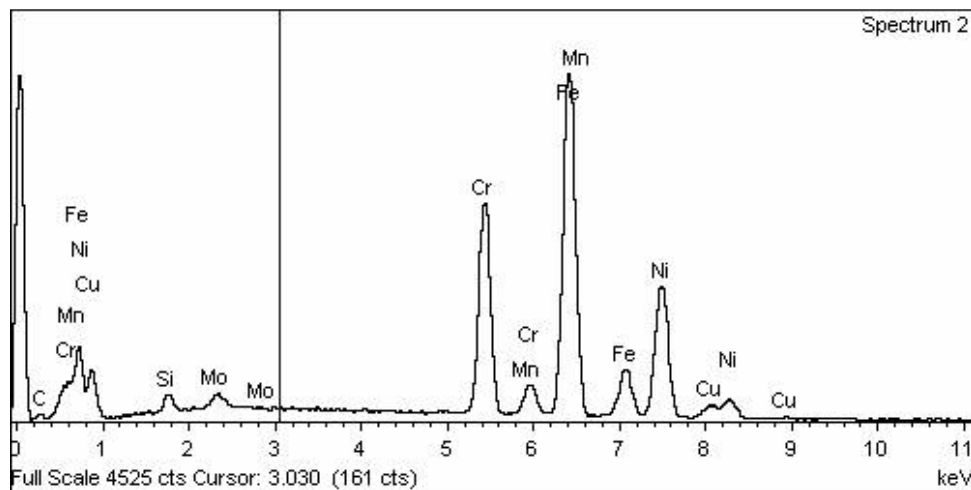


Figure 5: Energy Dispersive Spectroscopy spectrum.

Fracture Analysis

The fracture seen when the broken pieces of pump housing were analyzed was intergranular fracture. Triple points are the point where three grains meet and are characteristic of intergranular fracture. Two triple points can be seen in this material in Figure 6. This micrograph also shows signs of corrosion pits and spots on the surfaces of grains.

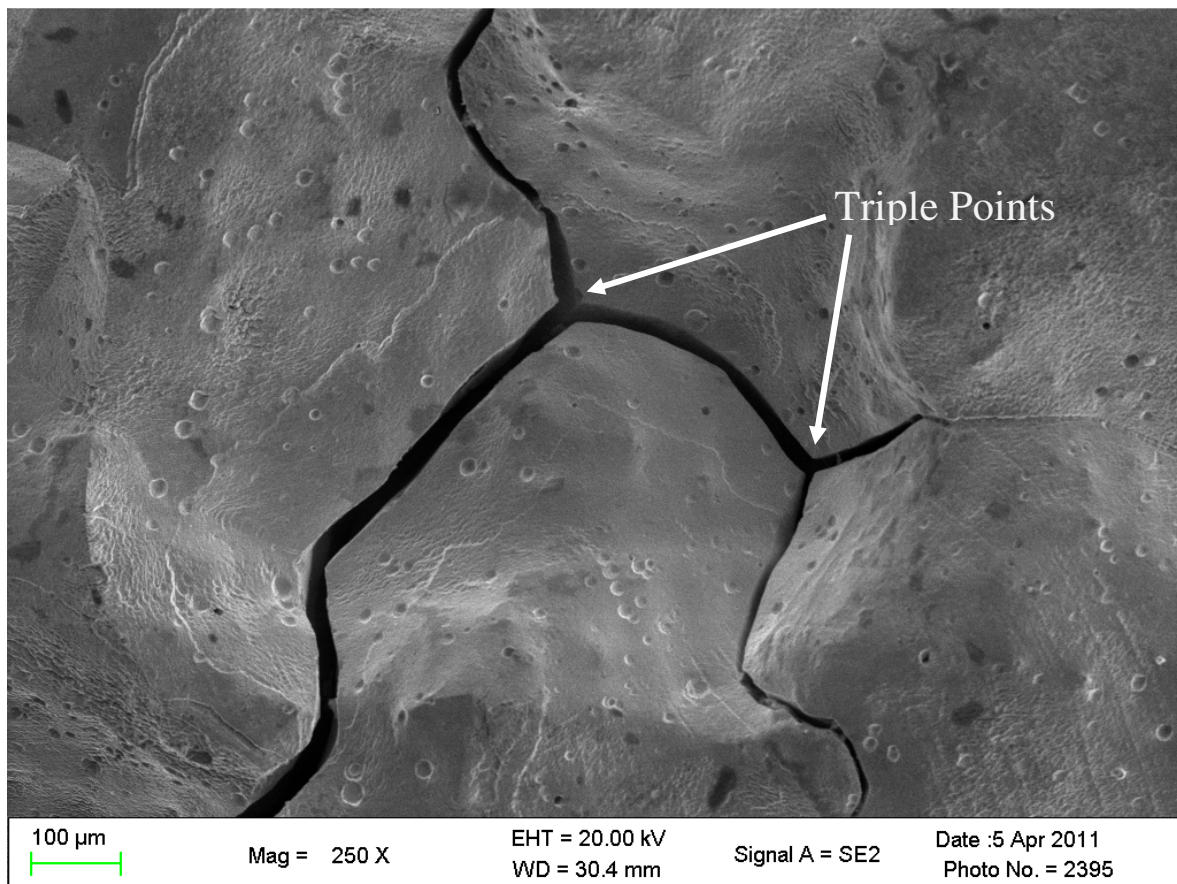


Figure 6: Micrograph taken at 250 x magnification shows intergranular fracture.

While these grain surfaces are smooth, other grains showed regular texture suggesting dendrites as shown in Figure 7. Some possible oxidation is also showing in this picture. Other parts of the fractured sample showed signs of corrosion on the surface grains as shown in Figure 8. None of these fracture surfaces shows signs of transgranular fracture such as microvoid coalescence, chevrons and other lines from crack propagation, or smooth flat faces from cleavage [2]. Intergranular fracture indicates that the bonds between grains were weaker than the grains themselves. If the grains were weaker than the grain boundaries, cracks would have traveled through them instead of around them. This is evidence for intergranular corrosion because this failure mechanism would have weakened the grain boundaries.

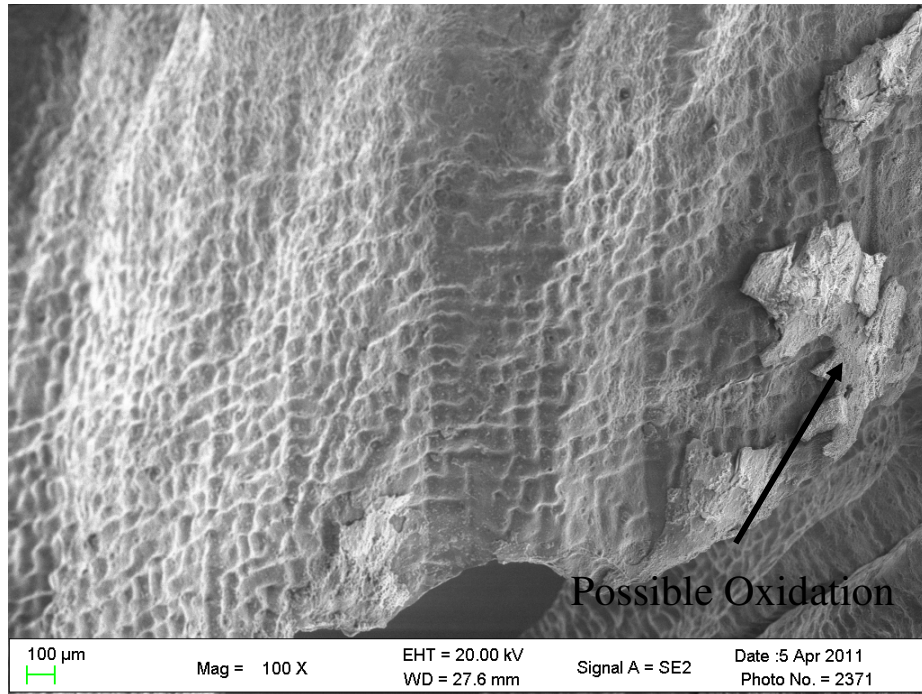


Figure 7: Micrograph taken at 100 X showing evidence of dendrites on grain surface.

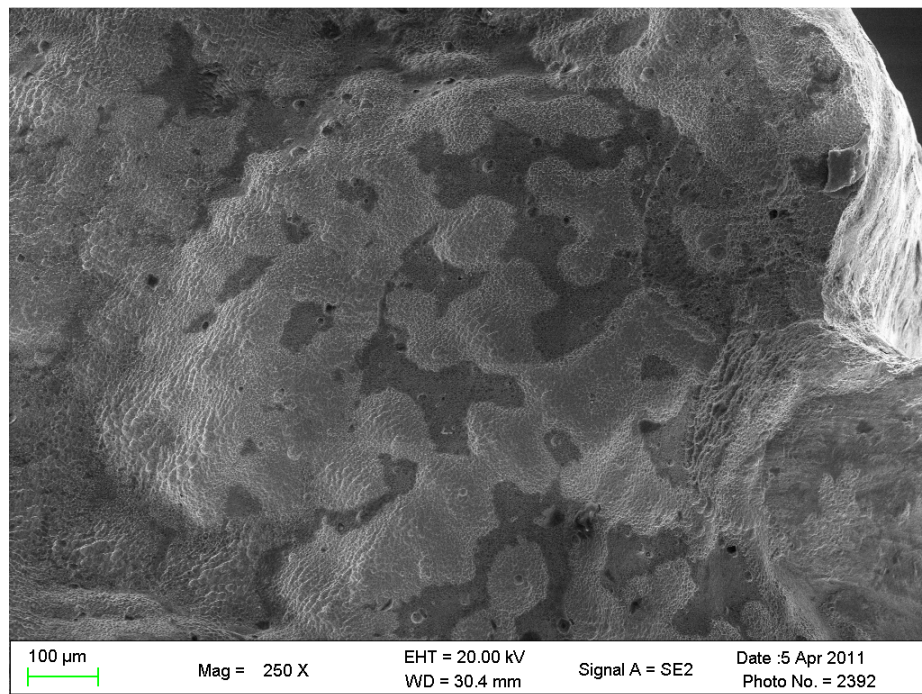


Figure 8: Micrograph taken at 100 x showing signs of corrosion on grain surface.

Metallography

A micrograph for the pump housing at 100x and 200 x can be seen in Figures 8 and 9. Dark spheres are most likely inclusions while the small clusters of spots may be carbides.

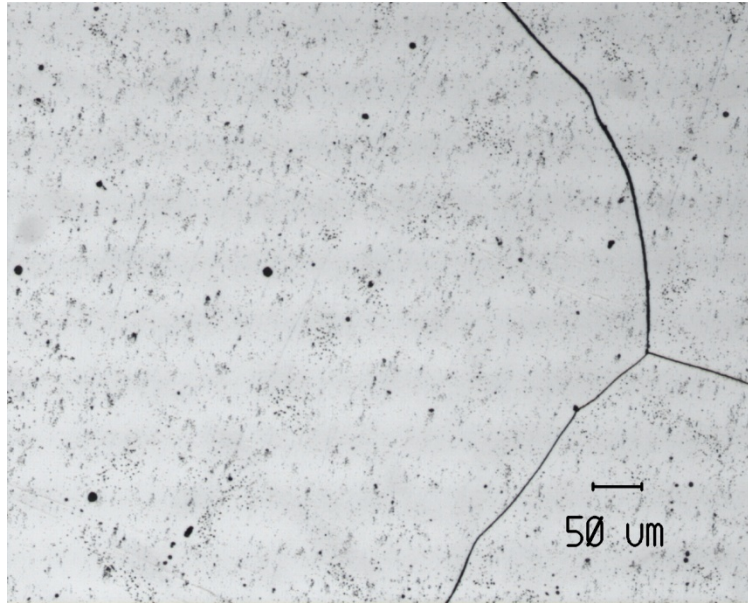


Figure 8: Micrograph of pump steel taken at 100 x magnification with oxalic etch.

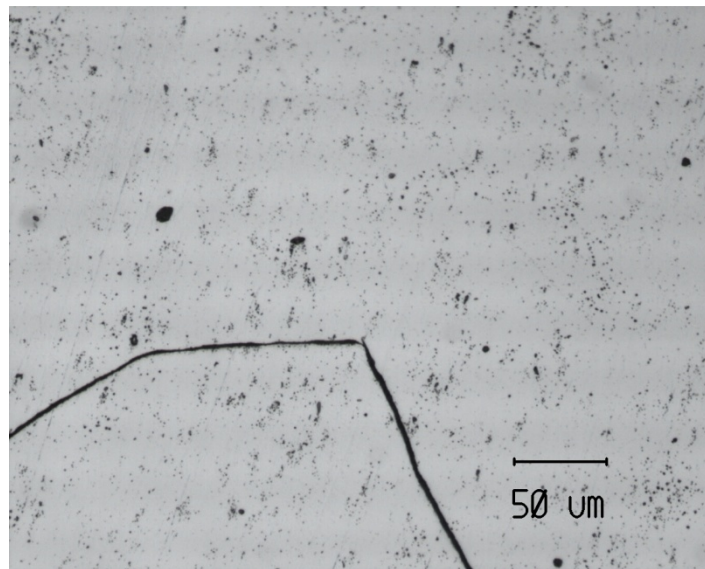


Figure 9: Micrograph of pump steel taken at 200 x with oxalic acid etch.

A micrograph for CN7M showing a typical as cast microstructure is shown in Figure 10. This shows grain boundaries and inclusions. The microstructure for a sample of CN7M with the correct solution treatment can be seen in Figure 11. This shows some inclusions, but no carbides. A sample with incorrect heat treatment can be seen in Figure 12. This shows significant carbide in the grain and in the grain boundary.

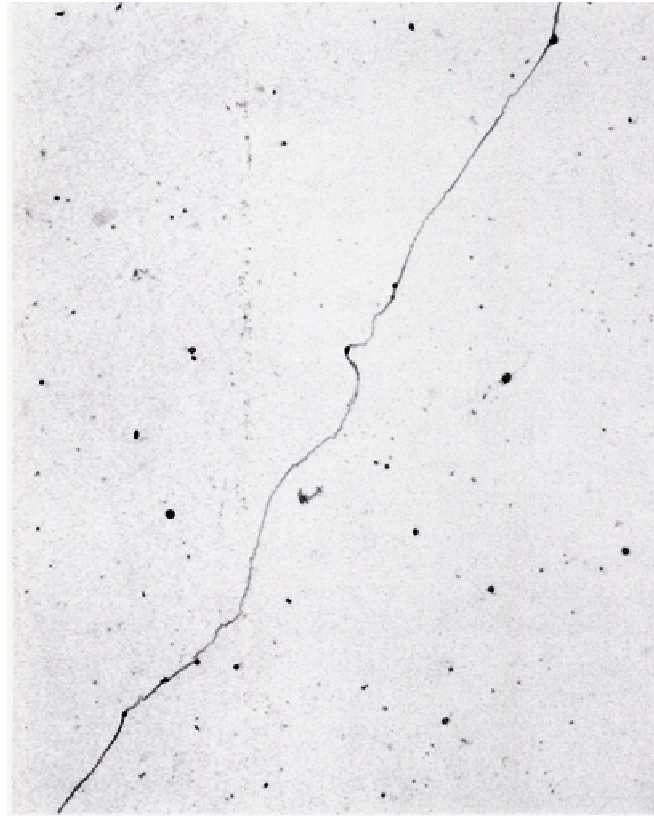


Figure 10: As-cast sample at 200 x magnification etched with Oxalic acid. Picture shows austenite with dispersed inclusions and carbides along grain boundaries.

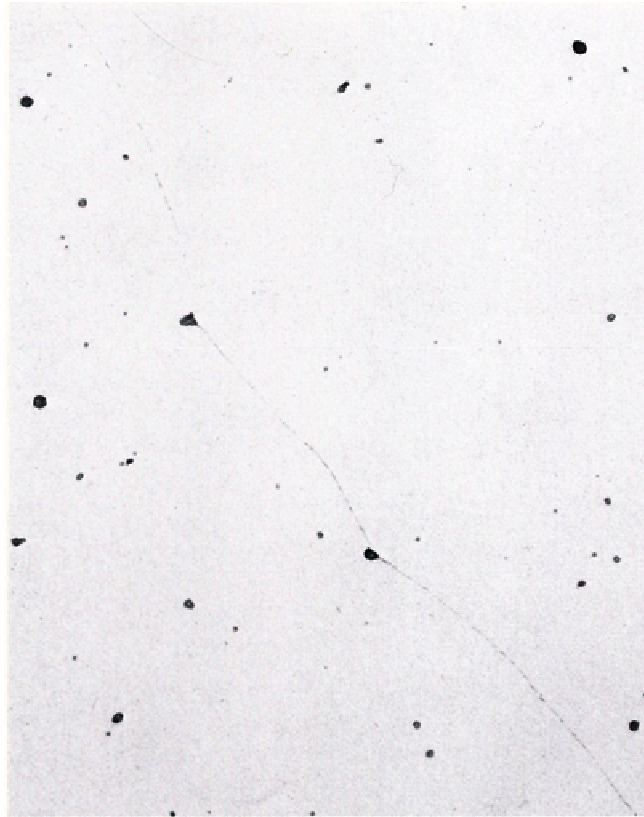


Figure 11: Solution treated 1 hour at 2150 °F (1175 °C), water quenched (correct heat treatment) shown at 200 x magnification showing austenite with dispersed inclusions. Oxalic acid etch.



Figure 12: Improper heat treatment, 15 minutes at 1800 °F (980 °C), water quenched shown at 1000 x magnification shows grain boundary and dispersed carbides in austenite matrix. Oxalic acid etch.

Conclusion

The purpose of this project was to determine the cause of failure for a leaking CN7M stainless steel pump housing. Chemical analysis showed that the composition was similar to the standard for CN7M, and looking at a fractured surface showed that the grain boundaries were weaker than the grains causing intergranular fracture. Metallography was done and showed carbides within and around the grain boundaries which made the pump susceptible to intergranular attack. Intergranular corrosion led to cracking which caused the pump to leak.

References

1. Bates, Charles E. & Larry C. Tillery. Atlas of Cast Corrosion-Resistant Alloy Microstructures. Steel Founders' Society of America. 1985. pp 92 – 97.
2. Callister, W. D. *Materials Science and Engineering and Introduction*. 7th ed. John Wiley & Sons. 2007. pp 212, 364.